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Groundwater Irrigation and Energy Nexus in Central Punjab – Trends and Analysis

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Abstract

The energy consumption patterns of agriculture in central Punjab have changed enormously during the past two decades. This study investigates on how the declining groundwater levels and increased groundwater usage has influenced the energy requirements for irrigation, in Central Punjab. The increased groundwater use by 386.4 mm in last 15 years (1998- 2013) has resulted in rapid decline of groundwater levels from 9.15 to 18.03m in Central Punjab. Consequently, the energy requirement had increased by 4845.1 MkWh (90%), since 1998. Blocks Bhawanigarh, Sangrur and Sunam were identified as the critical blocks of central Punjab and should be targeted for groundwater management and to reduce energy crisis. The study also elucidates that for each meter fall of groundwater level in central Punjab, there is additional energy requirement of 18.05 Wh/m³ of groundwater extracted causing an economic loss of 33.2 million Indian rupees.

Keywords: Energy consumption, Groundwater levels, Groundwater usage, Groundwater pumping, Central Punjab

JEL Classification: Q13, Q25

Introduction

Groundwater pumping has increased to meet the growing demand for water in agriculture, resulting in declining groundwater levels and increasing on-farm energy crisis worldwide. Punjab is agriculturally most productive state of India with more than 85 per cent of its land is under agriculture and stands at an extreme end of over-exploitation of groundwater (Gupta, 2011). At present, the State has 98 per cent of the net area sown as irrigated. The major crops of the region are rice and wheat which covers nearly 75 per cent of the total cropped area in the state. The surface water resources are not sufficient to meet the total irrigation needs. The percentage irrigated area from canals and tube wells in the state is 28 per cent and 72 per cent respectively. This has led to over-exploitation of groundwater resources which are declining at an alarming rate of 51.5 cm/year (Kaur *et al,* 2011). Consequently, there is a huge pressure on the groundwater aquifers. Among 138 blocks, 110 blocks are over exploited, 3 blocks are critical and 2 blocks are semi critical and only 23 blocks fall under safe category (CGWB, 2011).

One of the major reasons in large scale exploitation of this resource is the free electricity coupled with uneven distribution of rainfall. In Punjab, power for agriculture was totally free from 1997 to 2002 and from 2005 onwards. As a result, the number of tubewells has increased from 1.92 lakh in 1970 to 13.83 lakh in 2013. The power consumption was 7532 MkWh in 1998 and has increased to 11000 MkWh in 2014 (GoP, 2014). The genesis of this unique energy-irrigation nexus in Punjab has huge financial implications to the State and is also disturbing the socio-economic conditions of the farmers.

Many attempts have been made in the recent years to understand the groundwater-energy nexus in Punjab (Sarkar and Das, 2014 and Shah *et al,* 2004). However, neither the groundwater decline nor the energy requirement is uniform in time and space. The

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most problematic area is the central zone which covers about 50 per cent of area of the State and continues to face maximum groundwater decline rate and negative water balance owing to intensive cropping and 98 per cent of area being under paddy and wheat (Chawla *et al,* 2010).

The present study investigates the influence of deepening groundwater levels and increased extractions rates on the energy demand in central Punjab, with an aim to identify the most affected blocks that needs to be targeted for groundwater and energy conservation in central Punjab.

Data Sources and Methodology

Description of study area

The central Punjab covers 18000 sq. km. which represent about 36 per cent of the total area of Punjab and in this study the region was divided into four zones (Fig. 1) namely Upper Bari (UB-III), Bari Doab (BD-III), Sirhind Canal (SC-III) and Bakhra Main (BM-III). The demarcation of zones was based on Agro-Climatic Zones (ACZ). These ACZ are further grouped into 3 main groups (from the rice crop cultivation management and soil and physiographic similarities point of view) are Sub Mountain Region (ACZ-I and II), Central Plain Region (ACZ-III) and Southern-Western Region (ACZ-IV & V). The altitude and land slope varies from 104 meters in the west to 307 meters in the south east above mean sea level (MSL) and north east to south west, respectively.

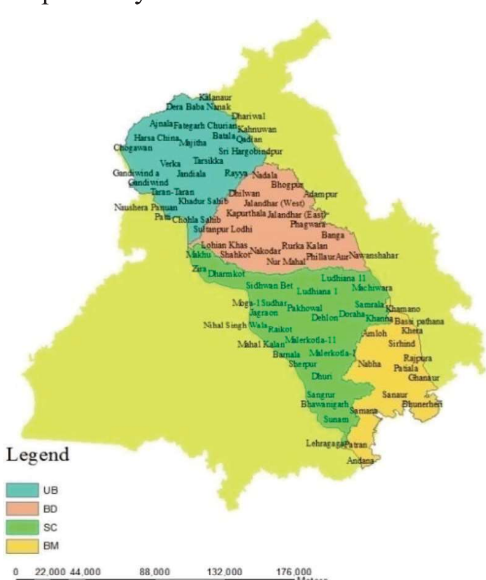

Figure 1. Map of the study area

The climate of central Punjab is classified as semi arid and hot which is mainly dry with very hot summers and cold winters except during south west monsoon season. The average annual precipitation ranges from 102 mm-900 mm, which is unevenly distributed over the area. The south west monsoon sets in from last week of June and withdraws in end of September, contributes about 78 per cent of annual rainfall and the rest of 22 per cent rainfall is received during non-monsoon period in the wake of western disturbances and thunder storms. Generally, rainfall in central Punjab increases from southwest direction to northeast direction. The mean minimum and maximum temperature in the area ranges from 6.1ºC to 40.4ºC during January and May or June respectively.

Estimation of energy requirement

The electric energy required for groundwater pumping was calculated as per the methodology described by Nelson and Robertson (2008) and partially by Shah (2009).

$$\text{Energy (kWh)} = \frac{m*g*h}{3.6*10^{6}*\eta_{eff}(\%)*(1-\text{T\&D losses}(\%))} \quad (1)$$

Where,

h is the total dynamic head (m);

m is the mass of groundwater lifted per annum (kg);

g is acceleration due to gravity (m/s^2);

T&D losses (%); the year wise T&D losses were taken from Planning Commission annual report, Punjab.

η_{eff} is the efficiency of pumpsets (%)

In case of diesel pumpsets, efficiency was defined as the ratio of the power imparted on the fluid by the pump in relation to the power supplied to drive the pump. In the overall efficiency in diesel operated pump sets was taken as 12 per cent (equation 1).

The energy required to pump water depends on numerous factors including the source of pumping, total dynamic head (based on water lift, pipe friction, and system pressure), the water flow rate and the pumping system efficiency (Whiffen, 1991). Water table depth for pre-monsoon (June) season was obtained for nearly 500 observation wells installed at different locations in central Punjab. Krigging interpolation technique was used for modeling spatial patterns and assessing uncertainty (Delhomme, 1978; Virdee and Kottegoda, 1984; Kumar, 1996 and Kumar and Ahmed, 2003) in prediction of block-wise water table depth for the period 1998 to 2013. The total pumping head was the sum of the initial water table depth, drawdown, seasonal fluctuations (20 per cent) and friction losses (equation 2).

h=initial water table+20% of initial water table+ drawdown(3m)+friction losses (1m) (2)

The quantity of groundwater pumped during monsoon and non-monsoon period was obtained on the basis of number of tube wells and draft norms obtained from Department of Agriculture, Punjab. Since these norms were recommended for normal annual rainfall conditions, the total draft values were modified based on amount of annual rainfall. The draft values were increased/ decreased by 10 per cent whenever the annual rainfall was usually low/high. The multiplication factors chosen were 1.31, 1.20, 1.10 and 0.95 for the rainfall less than 220mm, 220-320 mm, 320-420 mm and greater than 420 mm, respectively (Aggarwal *et al,* 2009).

Tube well draft (in ha-m) = number of tube wells*unit draft (in ha-m) (3)

For deriving a relationship between energy requirement and groundwater depth per unit quantity of groundwater pumped, equation 4 was used.

$$E_r\ (Wh/m^3) = \frac{E_e * 10^6 * 10^3}{G_w * 10^4} \qquad (4)$$

Where, E_r is the energy required per unit of groundwater extracted (Wh/m^3);

E_e is the mass Energy required MkWh;

G_w is the groundwater extracted (ha-m);

A regression model was then fitted between energy required per groundwater extracted and groundwater depth. This relationship is further used to calculate the total economic loss by agriculture in 2013 by multiplying it with an average rate of per unit of electricity i.e. by 4.56 rupees per KWh.

Results and Discussion

Groundwater-Energy nexus in central Punjab

The average water table depth of central Punjab was 9.15 m in 1998 and 18.04 m in 2013, indicating the annual fall rate was 59.20 cm/year. In UB-III, BD-III, SC-III and BM-III, the water table depth declined from 7.7-14.4, 7.7-14.1, 9.8-20.8 and 10.8-22.3 m with an annual fall rate of 44.6, 42.6, 73.3 and 76.6 cm/year respectively during the study period. Thus, amongst the four zones, BM-III showed the maximum decline rate. The rate of decline in water table in UB-III was linear until 2004 and afterwards, it showed a fluctuating trend (Fig. 2).

Similarly, the time series analysis of groundwater draft was highest in SC III zone during the monsoon period (Fig. 3a). This was attributed to high tube well density in SC-III zone. The groundwater draft was more or less same in BD-III and BM-III with an average pumpage of 704.6 and 781.1 mm respectively. Similarly during non-monsoon season, it was more or less same in BD III and SC-III with an average discharge of 397.7 and 398.1 mm, respectively (Fig. 3b).

The decline in groundwater levels and increase in groundwater draft is directly linked to the energy requirement for water extraction. The energy requirement of central Punjab by groundwater pumping

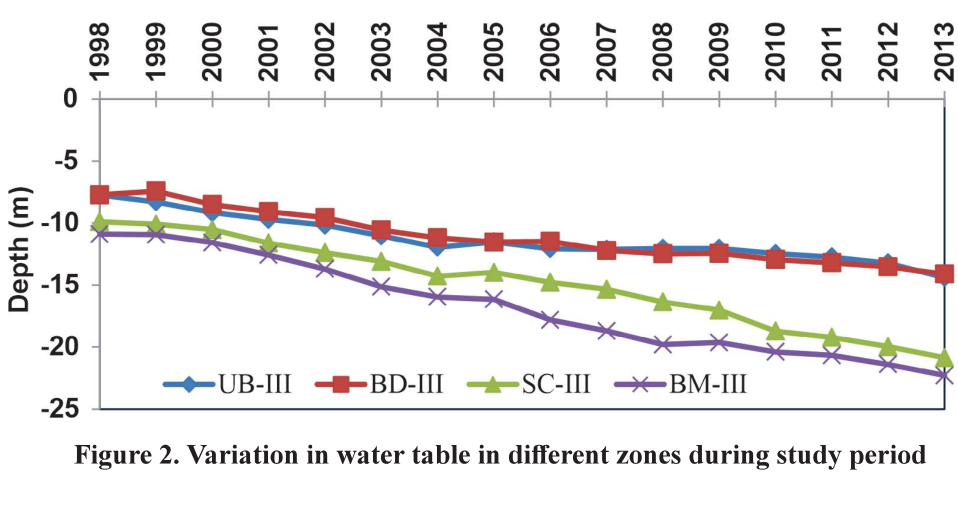

Figure 2. Variation in water table in different zones during study period

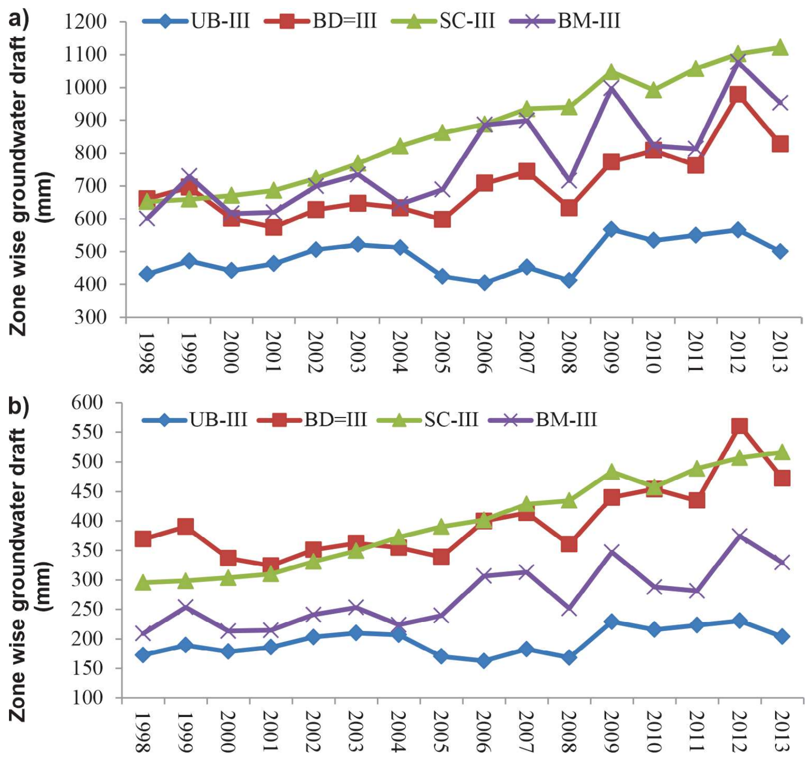

Figure 3. (a) Monsoon (b) non-monsoon season groundwater draft (mm) in different zones

was 3074.46 MkWh in 1998 and 7919.64 MkWh in 2013. The energy requirement was more or less same in BD-III and BM -III with an average requirement of 750 and 803 MkWh respectively during monsoon period whereas energy requirement during non- monsoon period was more or less same in UB III and BM III with an average of 211 and 275 MkWh. The temporal analysis of energy requirement observed the linear increase in SC III zone during the study period

The change maps of water table, groundwater draft and energy requirement are shown in Fig. 4. Overall, the region experienced a fall of 8.89 m in the water table; an increase in groundwater draft from 26280.48 ha-m in 1998 to 39402.41 ha-m (50 %) resulting in increased energy requirement from 3074.5 MkWh in 1998 to 7919.6 MkWh (90%) in 2013. Comparison of groundwater use in agriculture and the trend of water table changes show blocks with higher rate of groundwater table decline and higher rates of energy requirement are mostly those that are more dependent on groundwater for irrigation. Blocks namely Malerkotla I, Malerkotla II, Sangrur, Bhawanigarh, Sunam and Sherpur of SC-III and Samana and Nabha of BM-III were the most energy consuming blocks with an increase of more than 150 MkWh during the study period. The figures showed that blocks Bhawanigarh, Dhuri, Sunam and Sangrur of SC-III, Amloh and Samana of BM-III witnessed a decline of more than 12m in water table.

A linear relationship was observed between the groundwater depth and energy requirement for central Punjab (Fig. 5). Therefore, if water table drops by another meter in central Punjab, the region will be consuming 18.05 Wh of more energy for every 1000 litres of groundwater extraction. This mounts to additional burden of 33.2 million rupees on the State finances, assuming that there is no further increase in number of tubewells.

Conclusion and Policy Implications

Groundwater pumping in Central Punjab consumed 7919.64 MkWh of electricity. A massive change in energy requirement in central Punjab has been recorded in various blocks from 1998 to 2013. A direct relationship is identified in energy usage and groundwater depletion, it means greater the depletion of groundwater resources greater is the consumption of energy. The changing rainfall pattern and mismanaged canal system has also added to the problem positively. Transformation in

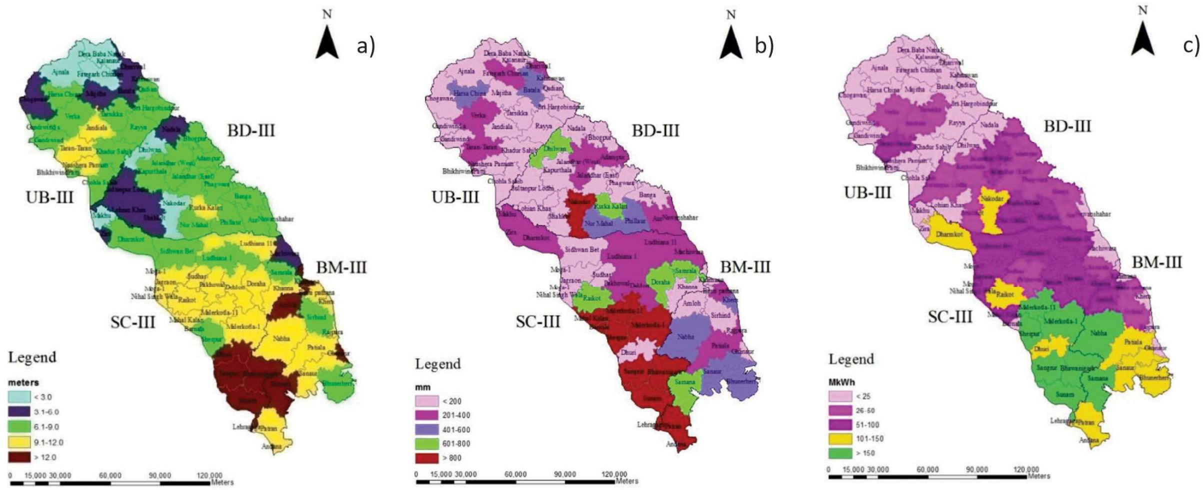

Figure 4. Change maps of water table, groundwater draft and energy requirement in central Punjab from 1998-2013

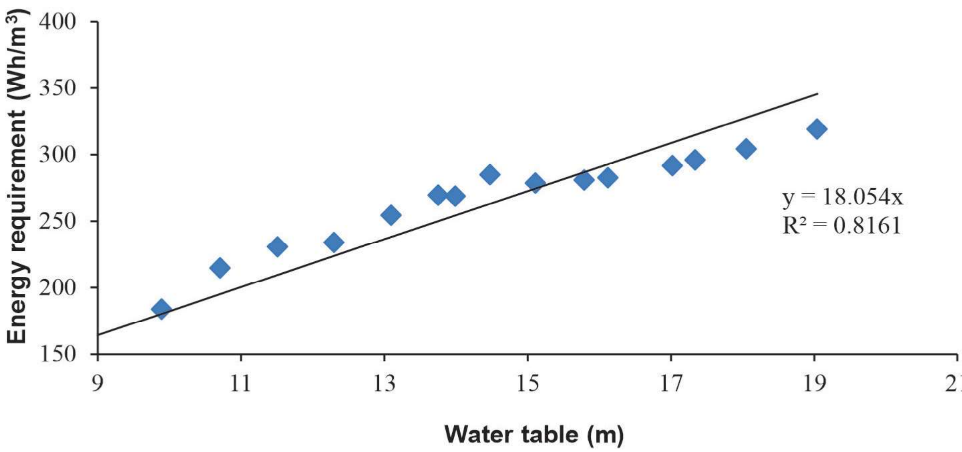

Figure 5. Relationship between energy requirement per groundwater extracted and water table in central Punjab

agricultural practices is the most highlighted factor for aquifer degradation. The Punjab government is completely attentive of depleting groundwater table. However, the government decision to supply of electric power for irrigation to the farmers without charges is aggravating the problem and the area under paddy cultivation is also not reducing. The Electricity Board supply power to agriculture sector and claim subsidy from the State Govt. based on energy consumption. The energy needed for different lift heights is different and the correct estimation of consumption greatly depends upon the cropping pattern, ground water level, seasonal variation, hours of operation etc. The study concluded that 18.05 Wh of more energy is required to lift 1000 litres of groundwater for metre decline in groundwater levels.

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